The Effectiveness of Specific Weight Training Regimens on Simulated Aerial Combat Maneuvering G Tolerance

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To assess the effectiveness of muscle-strength (weight training) on simulated aerial combat maneuvering (SACM) G tolerance, seven young men were exposed to a 12-week program of whole-body weight training in which were measured, strengths of various muscle groups, body circumferences, body mass, and the percentage of body fat. The magnitudes of the weights used in training were used to measure muscle strength and were compared and correlated with each subject's SACM tolerance—defined as the total time that a subject could withstand continuous exposure to a 4.5 and 7.0 + G_z centrifuge profile using fatigue as his voluntary endpoint. Chest and biceps circumferences increased 4.2% and 3.1%, respectively; abdomen and thigh circumferences did not significantly change; body fat decreased 16.8%; and body mass increased 2.3%. Abdominal (sit ups) and biceps (arm curl) strengths increased 99% and 26.2%, respectively, and were highly correlated with SACM tolerance time ($p<0.01$); leg (leg press) and chest strengths (bench press) made less significant contributions to the SACM tolerance time. A net increase in SACM tolerance times of 53% resulted from weight-training. Multiple regression analysis of all four muscle groups between weeks 1 and 12 with the SACM tolerance had a correlation of determination of 0.61.

IT IS WELL known that for pilots of high performance aircraft (e.g., F-15 and F-16) to tolerate high accelerative (G) forces, they must perform a coordinated muscle tensing effort known as the anti-G straining maneuver (AGSM). This voluntary maneuver is very demanding physically and is directly related to the ability of the pilot to perform the anti-G aspects of the aerial combat maneuver (ACM). It is therefore of operational importance to improve the aircrew's ability to perform the anti-G straining maneuver. Since this maneuver is a learned effort, training is extremely important. However, once the optimal level of anti-G straining has been accomplished through training, ACM tolerance can be increased through a physical conditioning program by increasing muscle strength. This approach as a method to increase ACM tolerance was developed by our laboratory (6) and later confirmed in a separate study by another research group (10).

Our laboratory found that a net increase in G tolerance, as measured using a simulated aerial combat maneuver (SACM), of 53% resulted from a 12-week muscle strength training program (6). Similarly in the other study in which a less vigorous 11-week strength training course was used, a 39% increase in the SACM was found (10).

Since increased muscle strength significantly improves SACM tolerance, the relationships of specific muscle groups to the increased SACM times are of considerable importance in developing an efficient weight training regimen. Consequently, strengths of various individual muscle groups were correlated to individual SACM tolerance times as was body confirmation and these results are reported herein.

MATERIALS AND METHODS

The results of this study were determined from the weight-trained groups of acceleration subjects (n = 7) involved in a much larger study, the subject of an earlier article (6). In that study, three groups of volunteer subjects participated over a 12-week period of time. One group did aerobics training by running,

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and significantly increased their maximum aerobics capacity ($\dot{V}O_{2max}$). Another group trained with weights four major muscle groups involving the arms, chest, abdomen, and legs. The third group was the controls and as such did not participate in any formalized physical training regimen.

G-Training: Since changes in SACM tolerance times were the primary criteria of their study, training subjects to their optimal level of G tolerance before the experiment began was essential. Consequently, five weeks were devoted to training the subjects to tolerate the SACM type of G exposure to their maximum capability. During this time period, each subject was given six training exposures on the centrifuge. During the 5-week training period all subjects were instructed not to engage in regular or strenuous physical activity. At the end of the centrifuge training period the subjects began their weight training program.

Weight Training: The weight trainers worked out in a ventilated gymnasium once each day in the morning. Although the gymnasium was not air-conditioned, the ambient temperature in the morning during their workouts for the entire study never exceeded 27°C.

Two circuits of common exercises were specified for training. Each circuit was used every other day so that a two day cycle would exercise all major muscle groups. To complete a circuit each exercise was performed for three sets with a 3-min rest between sets.

During the first training session, the 1 rep maximum (IRM) weight was determined for each of the lifting motions. During the second training session, set 1 was for 10 reps using 70% of the IRM weight. Sets 2 and 3 used 80% of the IRM weight with a limit of 10 reps in each set. The weight remained constant until the subject could complete 10 reps on set 3. When this occurred, the subject would add 5 lb to the "80%" weight for the upper body motions, and 10 lb for the lower body motions for the next training session. Appropriate amounts were added to the "70%" weight to maintain its relative level. These weights would be used until the subject once again could complete 10 reps on set 3. This regimen continued for the entire training program.

Muscular Strength: Muscular strength of the weight trainers as determined by recording the training weight for four major exercising muscle groups—arms, chest, abdomen, and legs. These weight lifting motions were the arm curl, bench press, sit up, and leg press, respectively. These muscle groups are representative of the major muscular functions which would appear to be most useful in the performing the AGSM. To quantify muscular strength, throughout the study, the "80%" training weight value was most useful.

G-Tolerance: Acceleration tolerance was determined using the USAF School of Aerospace Medicine human centrifuge (3). The subject, fitted with an anti-G suit (USAF CSU-12/P), was positioned in an aircraft seat (13° seatback angle) in the gondola of the centrifuge. During G exposure the anti-G suit was inflated at 1.5 psi $\cdot$ G^{-1} beginning at 2 G. The subject was monitored using two ECG channels, an ear oximeter for continuous measurement of arterial saturation, closed circuit television, and two way audio communication. A medical monitor and a central observer in the control room observed the subject at all times during a centrifuge run.

The SACM tolerance consisted of alternating 15-s plateaus of 4.5 and 7.0 G continuously until each subject's voluntary endpoint of fatigue was reached. Upon reaching his point of fatigue, the subject stopped the centrifuge by releasing the brake held in his left hand. A subject's tolerance time was defined as the time spent continuously at a G load greater than 2 G. Details regarding this type of G-tolerance determination are available to the reader (4). Tolerance to the SACM profile was measured on weeks 1, 3, 4, 6, 8, 10, and 12 of the protocol.

Body Conformation: To determine weight-training effects on specific muscle masses, an experienced technician periodically measured body mass and the circumferences of the chest, abdomen, dominant flexed biceps, and the dominant thigh. These measurements were made on weeks 1, 4, 8, and 12 of the study. A whole body volumeter (1) was used to determine body composition on weeks 1, 8, and 12.

RESULTS

The specific training effects relative to changes in body conformation and strength for the weight-trained subjects are shown in Tables I and II. The respective 4.2% and 3.1% increases in chest and flexed-biceps circumferences indicate that the muscles of the thorax and upper arm increased in size. Although no significant changes were seen in the abdomen and thigh, the loss of abdominal and muscle fat would attenuate any circumference change resulting from an increase in lean mass. We didn't expect great changes in muscle mass using these weight lifting regimens. Our program was tailored for developing strength not mass.

Over the 3-month strength-training period, the subjects increased their body mass by 1.6 kg. This

TABLE I. THE EFFECTS OF 12 WEEKS TRAINING ON BODY CONFORMATION COMPARING WEEK 1 (PRE; BASELINE) AND WEEK 12 (POST) USING PAIRED t-TESTING. SHOWN ARE GROUP MEANS ± S.E. AND % CHANGE IN THE PARAMETER.

Parameter	Pre[a]	Post[a]	%Δ[b]	p[c]
Chest (cm)	92.4 ±1.95	96.3 2.09	4.2	<0.01
Abdomen (cm)	79.8 2.09	80.4 2.22	0.8	N.S.
Biceps (cm)	31.8 0.55	32.8 0.54	3.1	<0.01
Thigh (cm)	56.5 1.87	56.4 1.98	−0.2	N.S.
Body Mass(kg)	69.6 2.7	71.2 2.9	2.3	<0.01
Body Fat(%)	16.7	13.9	−16.8	<0.01

[a] = sizes are circumferences; [b] = [(Post − Pre)/Pre] X 100 = %Δ; [c] = paired t-test; N.S. = not significant, p>0.05.

TABLE II. THE EFFECTS OF 12 WEEKS WEIGHT TRAINING COMPARING WEEK 1 (PRE; BASELINE) AND WEEK 12 (POST) USING PAIRED t−TESTING. SHOWN ARE GROUP MEANS ± S.E. AND % CHANGE IN THE PARAMETER RESULTING FROM THE TRAINING PROGRAM.

Weight Trainer's Strength				
	Pre[a]	Post[a]	%Δ[b]	p[c]
Arm Curl	60.0 4.63	75.7 3.69	26.2	<.01
Leg Press	282.1 18.25	402.9 25.47	42.8	<.01
Bench Press	102.9 8.08	130.0 11.95	26.3	<.05
Sit up	30.6 3.50	60.9 7.79	99.0	<.01

[a] = Mean ± S.E.; Pre = Baseline (week 1); Post = End of Training (week 12), strength is in pounds; [b] = [(Post − Pre)/Pre] X 100 = %Δ; [c] = Paired t−test.

change was consistent during the course of the study, which resulted in a significant correlation coefficient ($p<0.01$) and the following regression:

$$BM = 69.6 + 0.159\ t \qquad \text{(Eq. 1)}$$

where: BM = body mass (kg), and t = time in weeks.

Eq. 1 suggests that the weight trainers gained about 0.16 kg of body mass per week during the experiment. As shown in Table I, this gain is a function of a net loss of body fat—1.7 kg total fat loss per subject—resulting in an increase in lean body mass of 3.3 kg per subject.

The muscle strength for the abdominals increased rapidly during the study, so the weights used in the sit up motion per individual subject were followed on a weekly basis (Fig. 1). Unexpectedly, after week 5 of the training schedule, the weight trainers developed into two groups relative to muscle strength of abdominal

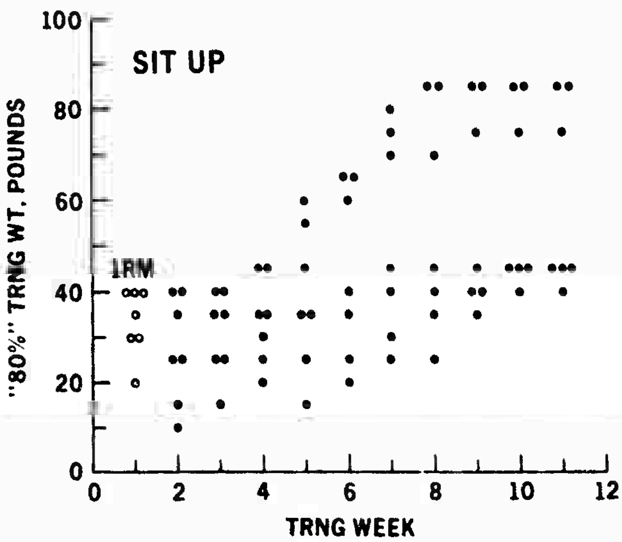

Fig. 1. Individual training weights are shown for each week of the study. It appears that near the middle of the schedule (week 6) 2 groups developed relative to abdominal strength—the strong group used 80 lbs for training whereas the other groups had an 80% IRM of 40 lbs.

muscles. At this time, three of the seven subjects rapidly increased their abdominal strength which then appeared to plateau during the last 3 weeks of the study. This stronger group was training with approximately 80 lb (80% 1 rep maximum); whereas the other, weaker, group used 50% less training weight.

To ascertain if there was any relationship between muscle circumference and strength within the weight training group, correlation coefficients were calculated for chest and flexed biceps circumferences against bench press and arm curl training weights, respectively. Of these statistical comparisons, the only significant correlation ($p<0.05$) was the biceps circumference and arm curl weight which resulted in the following regression equation:

$$B = 27.8 + 0.065A \qquad \text{(Eq. 2)}$$

where: B = flexed biceps in cm; and A = arm curl weights (lb). The arm curl motion is a relatively simple motion involving the contraction of three primary muscle flexors. The size of the flexed-bicep muscle group therefore appears to have a high correlation with its strength, as measured with the weight being lifted in the curl motion. However, once again we stress that our training regimen was for muscle strength and not directed towards large changes in muscle mass.

To determine the importance of the four selected weight-training motions (bench press, sit up, arm curl, and leg press) in improving SACM tolerance, tolerance time was statistically compared by regression analysis to the 80% training weights for the first and last training weeks (weeks 1 and 12) combined (Table III). Of the four motions, significant correlations were found for SACM tolerance times with sit up and arm curl weights, with sit up giving the highest correlation coefficient. For the four motions, r and r^2 values were 1) sit up: $r=0.733$, $r^2=0.537$; 2) arm curl: $r=0.663$, $r^2=0.440$; 3) leg press: $r=0.438$, $r^2=0.192$; 4) bench press: $r=0.400$, $r^2=0.160$; all for 14 pairs each. These analyses indicate that abdominal (sit up) and upper arm strength (arm curl) are most important in ability to tolerate the SACM, with the single most important factor being abdominal strength (Fig. 2 and 3).

The coefficients of determination (r^2) specify that about 54% and 44% of the SACM tolerance times can be accounted for by abdominal and arm strength, respectively, whereas the leg and bench press each will determine less than 20% of SACM tolerance. However, the combined influence of all four training motions, as determined statistically through multiple regression ($r=0.78$; $r^2=0.61$), indicate the importance of the total muscle strength training program in determining SACM tolerance (Table III).

As noted earlier, the subjects separated into two subgroups with respect to sit up training weights (Fig. 1). The subgroups were compared for differences in their SACM tolerances—the three subjects with the sit up training weight of approximately 80 lb had a SACM tolerance mean of 522 s, whereas the weaker group had a SACM tolerance mean of 329 s (37% less than the stronger sit up group).

The exponential relationship of SACM tolerance with weight training strength was also determined using data

TABLE III. REGRESSION ANALYSIS FOR WEIGHT TRAINER'S SACM (G) TOLERANCE (SEC) AS A FUNCTION OF "80% OF IRM" TRAINING WEIGHT (LBS). EQUATIONS WERE CALCULATED FOR SIT UP AND ARM CURL ONLY FOR INCREMENTAL TRAINING WEEKS. MULTIPLE REGRESSIONS INCREASED CORRELATION COEFFICIENTS FOR ALL FOUR WEIGHT LIFTING MOTIONS.

	Rectilinear					Exponential			
Training Weeks	a[a]	b[a]	r(n)[b]	p[c]	Training Weeks	a	k[d]	r(n)[b]	p[c]
				Sit up					
Week 1	28.9	6.62	.709(7)	N.S.	Week 1	87.4	.030	.784(7)	<0.05
Weeks 1&4	−17.6	8.17	.749(14)	<0.01	Weeks 1&4	72.4	.035	.799(14)	<0.01
Weeks 1&8	187.7	1.91	.456(14)	N.S.	Weeks 1&8	187	.007	.454(14)	N.S.
Weeks 1&12	71.8	5.51	.733(14)	<0.01	Weeks 1&12	137	.017	.753(14)	<0.01
				Arm Curl					
Week 1	−63.5	4.93	.694(7)	N.S.	Week 1	58.0	.022	.762(7)	<0.05
Weeks 1&4	−153.6	6.28	.711(14)	<0.01	Weeks 1&4	38.5	.028	.775(14)	<0.01
Weeks 1&8	−27.9	4.50	.625(14)	<0.05	Weeks 1&8	74.4	.019	.682(14)	<0.01
Weeks 1&12	−224.0	8.04	.663(14)	<0.01	Weeks 1&12	45.2	.027	.775(14)	<0.01
				Multiple Regressions (weeks 1 and 12)					
Sit up + Arm Curl			.746(14)	<0.01	Sit up + Arm Curl			.810(14)	<0.01
+ Bench press			.780(14)	<0.01	+ Bench press			.862(14)	<0.01
+ Leg press			.783(14)	<0.01	+ Leg press			.863(14)	<0.01

a: $G = a + bW$ where G = SACM tolerance in sec; a = intercept; b = slope (rate of change in SACM tolerance); W = training weight (80% of 1 RM). b: r = correlation coefficient; n = number of pairs per determination. c: p = probability of chance occurrence (NS = not significant $p>0.05$). d: $G = ae^{kw}$ where G = SACM tolerance in sec; a = intercept; k = slope (rate of change in SACM tolerance); w = training weight (80% of 1 RM).

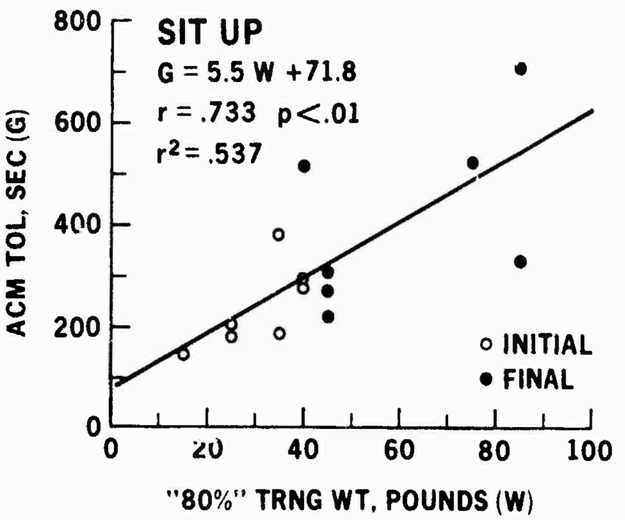

Fig. 2. The 80% training weights (function of IRM) for the sit up is correlated with SACM tolerance using the initial individual subject values (week 1) with their final values (week 12).

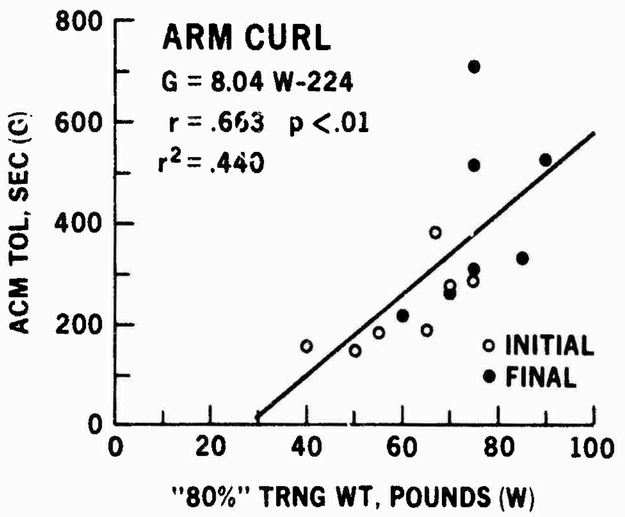

Fig. 3. The 80% training weights (function of 1RM) for the arm curl is correlated with SACM tolerance using the initial individual subject values (week 1) their final values (week 12).

from the first and last training weeks (Table III). Ln G was significantly correlated with sit up and arm curl training weights. These correlation coefficients were slightly greater than the rectilinear relationships between SACM tolerance times and the same training weights.

Although the correlation coefficients for SACM tolerance with both sit up and arm curl weights were increased, the value for arm curl was considerably enhanced—this exponential relationship suggests that biceps strength could be the major determinant in SACM tolerance. Again, bench press and leg press training appear to be minor contributors to SACM tolerance. The larger correlation coefficients, using exponential functions for each motion, suggest that tolerance times rise exponentially with an increase in muscle strength. Such a phenomenon could be expected since the function of workload duration and percentage of maximum possible workload utilized exhibit a similar relationship to that of Ln G and training weight (2).

As with the rectilinear function between SACM tolerance and training weight, the multiple regression demonstrates that SACM tolerance is a function of

total-body muscle strength. The correlation coefficient increased to 0.86, and the coefficient of determination increased from a 60% value for arm curl weight only to 75% for all four motions combined (Table III).

Further analyses were performed on the sit up and arm curl data relative to SACM tolerance times over the complete weight training program. Correlations of SACM tolerance times with sit up and arm curl training weights were determined for weeks 1, 4, 8, and 12 (Table III). In general, these correlation coefficients are statistically significant ($p<0.05$). A statistical significance is found in these data from week 1 for the exponential relationship of both muscle groups and begins with week 4 for the rectilinear functions. Thereafter, except for week 8 of the sit up data, significant correlations are found between muscular strength and G tolerance. Generally, except for weeks 1 and 8 of the sit up, the correlation coefficients for the exponential relationship are higher than those using rectilinear analyses. That SACM tolerance is strongly influenced by gross biceps and abdominal strength and not by net change in muscular strength is suggested by these statistical analyses; significant correlations occurred after only 4 weeks of weight training, when the training weights had not yet significantly increased.

A change in SACM tolerance as the result of a change in muscle strength was also considered by using statistical analyses on the changes in selected motions. No significant correlations were determined between change in SACM tolerance time and change in any of the training weights.

DISCUSSION

Data presented herein demonstrate that definite changes occurred in body conformation and composition as a result of the weight training program (Table I). These data also established a highly significant correlation between SACM tolerance time and biceps and abdominal strengths (Table III). These abdominal and biceps muscle masses are extremely important in supporting the circulatory system through the AGSM. Leg and thoracic muscle masses also influence both the AGSM and SACM tolerance time, but these data suggest a less important role.

The AGSM is a respiratory/muscular effort (3) used by pilots to maintain conciousness and adequate vision during high-G maneuvering flight. Muscular involvement for the AGSM involves the abdomen, diaphragm, chest, arms, and legs. The abdominal contraction prevents the pooling of blood in the abdominal region and aids in central venous return, thereby helping to maintain cardiac output. At the same time, the chest muscles are contracted to produce a forceful expiration; this is done against a closed or partially closed glottis so that the intrathoracic pressure is elevated, thus raising arterial pressure and maintaining eye and cerebral blood circulation. These abdominal and chest contractions are supplemented by tensing of the shoulder, arm, and leg muscles. The biceps group are used in pulling back on the control stick during high-G loading of an aircraft. The stick force required to maintain a high-G load is proportional to G and can be as high as 20 kg. In addition, tensing upper body muscles will reflexly increase systolic blood pressure (2,5)—a reflex which has been shown to increase relaxed G tolerance of 0.6 G with inflated G suit (3); however, at high G this reflex is considered minor in the physiologic requirements of the SACM tolerance. Leg tensing aids the anti-G suit in preventing pooling of blood in the lower extremities as well as aiding venous blood return to the central circulation. The importance of leg support in tolerating the SACM has been demonstrated in anti-G suit design changes—improved leg coverage such as found in the capstan-like anti-G suit improved SACM tolerances by 133% (8). It is thus evident that the kind of muscle involvement necessary for the AGSM is a static, high-intensity contraction that will support the circulatory system both mechanically and reflexly.

This kind of muscular tension is developed by training against high resistance (heavy weights). Of all the means available to a pilot to resist the effects of G, the one most important to him now is the one over which he has direct voluntary physical control—the anti-G straining maneuver.

In the ACM environment, the ability to perform an efficient AGSM is vital. The pilot must perform the AGSM with an intensity that will allow him to have adequate vision for his inflight situation, repeating the maneuver at approximately 3- to 5-s intervals for the duration of each G exposure. Several high sustained-G exposures may occur over a period of many minutes. To achieve such performance, the pilot must learn to "tailor" his muscular contractions for the intensity of the G load; i.e., he must not overstrain because of fatigue development. Tailoring this intensity to control the degree of loss of peripheral vision to approximately 50% is common among pilots regularly exposed to high G.

If a pilot has trained his muscles for strength and repeated high-intensity contractions, he will be able to maintain vision with a lower percentage of maximal voluntary contraction, thereby sustaining the contraction longer (2) and with a more rapid recovery (7). Additionally, even though specific information is not available, as an individual becomes stronger, he should be able to tolerate increasingly higher G loads while straining—not relaxed G tolerances.

Our study suggests that the most important muscles in determining G (SACM) tolerance are the abdominals and the biceps. These muscles probably are also the greatest contributors to the AGSM. The abdominals and biceps are not exclusive contributors, however as determined in a recent study, we assessed the value of increasing the strength of only the abdominal muscles for SACM tolerance. Abdominal muscle conditioning alone did not increase SACM tolerance, nor did it reduce the frequency of acceleration exposures necessary to maintain a stable high-G tolerance (9). Therefore, other muscles do contribute, and the synergistic effects of whole-body strength need to be assessed as well as the specific contributions of other specific muscles not considered in this study.

Recently, Tesch *et al.* (10) reported on a study similar to the one reported herein, only using fighter pilots instead of non-pilot volunteers. Their initial

SACM group tolerance of 245±33 s (X ± S.E.) was similar to our SACM time of 232 ± 33 s. Their subject population, after an 11-week strength training program, had a 39% increase in SACM time. Their subjects increased their strength 37–58% whereas our subjects had a range increase of 26 to 99%. However, it should be stressed that they used the Cybex II (Cybex II® Lumex Inc., New York) which is a speed-controlled dynamometer for training and testing whereas we used weights. In using the Cybex, they were able to measure anaerobic power which they found increased 14%. Also, they reported a highly significant correlation between G tolerance time and blood lactate concentration for the entire study; i.e., before and after training suggesting that their SACM tolerance time improved because of an increased anaerobic capacity. Since high intensity shunt duration work, such as lifting weights, has an anaerobic basis as well as SACM tolerances the reason for the direct correlation between them is apparent. However, since there appears to be only small changes in gross muscle mass (this report) and no changes in muscle fiber types nor capillary density, the basic reasons for the body to be able to expend more energy (the basis for a longer SACM tolerance) are not clear. Tesch *et al.* (10) speculated that the increased strength came from a neuromuscular adaptation—additional recruitment of high threshold motor units and better synchronization of motor units. The net result would be less muscular effort required to produce the same absolute force necessary to support the venous return system and reduce blood pooling during the SACM.

Regardless of the apparent inability to understand exactly the reasons for these results, the confirming evidence produced by Tesch *et al.* (10) is convincing to the extent that both laboratories recommend a weight training program for pilots to increase G tolerance.

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The conformational response of seven young men to a 12-week program of whole body weight training was assessed by measuring body circumferences, body mass and the percentage of body fat. Conformation and magnitude of the weights used in training are compared and correlated with each subject's Simulated Aerial Combat Maneuvering (SACM) tolerance. SACM tolerance was defined as the total time that a subject could withstand continuous exposure to a 4.5 and 7.0 $+G_z$ centrifuge profile as determined by his voluntary endpoint of fatgue. Chest and biceps circumferences increased. Abdomen and thigh circumferences did not change. Body fat decreased and body mass increased. Abdominal strength and biceps strengths were highly correlated with SACM tolerance times ($P<0.01$). Leg and chest strength made minor contributions to SACM tolerance time. Also the exponential relationship between muscle strength and SACM tolerance time gave higher correlation coefficients than did the rectilinear relationship. Multiple regression analysis demonstrated that SACM tolerance is a function of total body muscle strength.

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UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐

21. ABSTRACT SECURITY CLASSIFICATION
Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL
Russell R. Burton

22b. TELEPHONE NUMBER *(Include Area Code)*
(512) 536-3865

22c. OFFICE SYMBOL
USAFSAM/VNB